Regional Studies in Marine Science 2 (2015) 203–211

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Topographic features related to recent sea level history in a sediment-starved tropical shelf: Linking the past, present and future

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HIGHLIGHTS

- Revealed new geomorphologic evidences of sea level changes.
- Mapped a shelf valley used by local fisheries as a fishing ground.
- The MPA management should prioritize further topography surveys.

ARTICLE INFO

Article history:
Received 19 June 2015
Received in revised form
12 September 2015
Accepted 27 October 2015
Available online 30 October 2015

Keywords:
Sea level changes
Topography
Continental shelves
Artisanal fishing
Northeastern Brazil
Pernambuco

ABSTRACT

Hydroacoustic data were compiled in order to reveal geomorphologic evidences of sea level changes during the last 20 cal kyr BP at the Southern Pernambuco continental shelf (SPCS), Northeast Brazil. Bathymetric surveys were conducted between latitudes −8.71 and −8.98 at depths ranging from 10 to 100 m, covering the entire continental shelf and encompassing an area of 400 km^2 that is presently part of a multiple use marine protected area. The bathymetric data set was composed by 102.334 points and the topography was investigated based on: (a) 7 profiles perpendicular to the coastline; (b) a surface generated from a natural neighbor interpolation; (c) contour lines at intervals of 2 m; and (d) 107 cross-sections extracted from the surface generated. This effort allowed the identification of: (a) 5 steps located between depths of 16–20, 20–23, 25–30, 35–40 and 45–50 m and (b) a shelf valley with four topographically distinct segments. These features were interpreted as effects of the sea level changes and provided insights on the evolution of the SPCS. In general, its topography appears to have undergone little changes since the last glaciation. This provides applications that go beyond, and are not restricted, to the fields of science related to the recent geologic past. The preservation of these topographic features means maintaining a heterogeneous relief and therefore the potential for increased biogeodiversity. Shelf valleys are well known fishing grounds among the artisanal fleet. Efforts directed to map the benthic habitats associated to these topographic features may reveal their distribution, fragmentation and connectivity, which could in turn improve tools for fisheries management. This geologic diversity influences processes that affect the local biodiversity, and thus the related goods and services and is very important for researches related to the past, present and future of the continental shelf of the SPCS, a shallow-water sediment-starved environment.

1. Introduction

During eustatic sea level falls and lowstands, worldwide continental shelves were totally or partially exposed and shelf valleys were formed by fluvial and subaerial erosion (Conti and Furtado, 2009; Blum et al., 2013; Harris et al., 2014). Through these shelf valleys, sediments were carried to areas closer to shelf-edge and upper slope. In some cases, the sediment supply allowed the development of shallow-water depositional features such as deltas and sand ridges on present mid and outer shelf (Wagle and Veerayya, 1996; Gardner et al., 2007; Weschenfelder et al., 2008; Salzmann et al., 2013).

However, when sea level dropped below the shelf break, this change in base level could be responsible for development of canyons on shelf edge and slope by sediment flow down-cutting and headward erosion (Koss et al., 1994). These erosive features

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http://dx.doi.org/10.1016/j.rsma.2015.10.009
2352-4855/

are characterized by deep shelf-margin incisions (Harris and Whiteway, 2011). Their development and evolution are related to erosive turbidity flows derived from fluvial, shelf and upper slope sources and to slumping, slope failure and other mass wasting events (Pratson and Coakley, 1996; Ridente et al., 2007; Piper and Normark, 2009).

In this way, occurrence of shelf valleys and canyons are likely related to climate, fluvial and hydrological regimes during regressive periods and to the duration time in which sea level remained below the shelf break depth. During the Last Glacial Maximum (LGM), the global ice-sheets reached their maximum position and this huge continental ice mass was responsible for a decline in sea level to depths approximately 120 m below the present (Yokoyama et al., 2000; Clark et al., 2009).

Following the LGM, post-glacial period was characterized by the melting and collapse of continental glaciers resulting in a massive input of fresh water into ocean basins. This sea level rise has been documented by cores obtained from deep sea sediment, ice, coral terraces and salt marshes (Salzmann et al., 2013). These records reveal an overall long-term rise, punctuated by intervals of stabilization and rapid rise associated with meltwater pulses (Yokoyama et al., 2000; Hanebuth et al., 2000; Lambeck et al., 2002; Peltier and Fairbanks, 2006).

Thus, Holocene Transgression was not constant. There were periods of moderate or rapid rise intercalated by periods of relative sea level stabilization or slow rise. Terraces and steps are topographic features which can also be related to sea level changes and can reveal the location of shorelines formed during periods of sea level stabilization or slow rise (Corrêa, 1996; Wagle and Veerayya, 1996; Gardner et al., 2007; Salzmann et al., 2013).

Sediment-starved continental shelves are likely inserted in regions with low rates of precipitation and sedimentation, and thus have increased potential to preserve topographic features such as steps, shelf valleys and canyons. This work presents a compilation of data in an effort to provide more details on the topography of the Southern Pernambuco Continental Shelf (SPCS) and its connection to recent sea level changes.

The surveyed area is part of a multiple use marine protected area with an urgent demand for scientific information to management strategies. As such, the aim of this manuscript is to describe the topography of the SPCS and to discuss some insights into its evolution during the Quaternary period and its pertinence to the human use of the benthic habitats associated with its topographic features.

2. Study area

The SPCS is located in a distensive marginal domain of Pernambuco Basin, one of the basins of eastern continental margin of Northeast Brazil that is considered the last link between Africa and South America (Rand and Mabesoone, 1982). The Pernambuco Basin is related to the Pernambuco–Alagoas Massif and is bounded by the Maragogi High (south) and by the Pernambuco Shear Zone (PESZ) (north).

The study area comprises 400 km^2 along the continental shelf off the Tamandaré Bay and is bordered by the Formoso River estuary (north), Una River (south) and the continental shelf edge at depths of 50–60 m (east). There is also is the northern end of the Coral Coast Environmental Protected Area, which was created to preserve the social, economic and cultural character of artisanal fishing and to protect local mangroves, coral reefs and endangered species such as the manatee (*Trichechus manatus*) (Fig. 1).

The hinterland climate is semiarid, which leads to reduced sedimentation in the continental shelf. The study area is influenced by tidal creeks and five rivers. The Ariquindá, Passos and Formoso Rivers form the Formoso River Estuary, a sinuous coastal plain influenced by small continental discharges and tides up to 2.5 m high. South of Formoso River estuary lie the Mamucabas and Ilhetas Rivers, which are each less than 20 km in length and are perennial coastal rivers with parallel courses forming a single small estuary. Further south, the Una River is an exception because it is approximately 200 km long and contributes a significant fresh water discharge to the shelf.

Since the second half of the twentieth century, the continental shelf of Pernambuco has been described as a sedimentary surface with a gentle slope and a reduced width located in shallow depths with warm high-salinity waters (Kempf, 1969; Manso et al., 2003; Araújo et al., 2004). It is covered with biogenic carbonate sediments and typically considered to be a sediment-starved tropical continental shelf. Along the shallow continental shelf, conditions are favorable for carbonate secreting organisms, especially algae of genera *Melobesia*, *Lithothamnium*, *Halimeda* and *Udotea* (Kempf, 1969; Coutinho and Moraes, 1968).

On the shallower portion of the continental shelf of Pernambuco and Alagoas, the presence of beachrocks is a striking feature in the landscape. These sedimentary rocks are intertidal in the shallower parts, been exposed during low tides, while deeper lines remain completely submerged at the greater depths (Mabesoone, 1964; Laborel, 1970; Maida and Ferreira, 1997). In the region, conditions were favorable for reef environments to develop on top of these hard substrata, and they can also occur as individual pinnacles that extend laterally at the top (Laborel, 1970; Maida and Ferreira, 1997; Castro and Pires, 2001).

Hard bottoms are areas exploited by the artisanal fishermen with motorized or sailing vessels that operate across the continental shelf up to the slope (Ferreira and Maida, 2007). This small-scale commercial fishery represents an important source of income for local population (Ferreira et al., 1998). The fleet is composed of boats less than 12 m long with little to no technology for navigational assistance or locating fish (IBAMA, 2008), so fishers tend to return to known fishing grounds.

The area contains a shelf valley and submerged reefs, which are topographic features considered to relate to the Holocene Transgression (Michelli et al., 2001; Camargo et al., 2007). These features are fishing grounds well known to fishers in the region, and it is assumed that productivity of fisheries around such features probably is due to the presence of three-dimensional hard substrates capable of promoting complex environments that support a greater biodiversity.

3. Material and methods

In this study were compiled data collected by Michelli et al. (2001) and Camargo et al. (2007), and by the projects "Pró-Arribada—Reef Fishes Spawning Aggregations in Brazil: Subsides for the Environmental Licensing of E&P Activities", and "Mapping and Characterization of Emerged and Submerged Coral Reefs and Beachrocks at the Pernambuco Shore" (Fig. 2).

Michelli et al. (2001) provided data about the topography of the SPCS based on 740 bathymetric points distributed along 12 profiles spaced 2–3 km. Among these profiles, 4 reached the shelf break, 4 extended to the isobaths of 45 m and another 4 mapped the inner shelf. During this survey the hydroacoustic data were collected using an Odom Hydrographic Systems HYDROTRAC echosounder, operating at a 200 kHz frequency. The bathymetric data were manually registered at 3-minutes intervals using a GPS GARMIN 48. Analog sonograms were interpreted in order to classify the seafloor and identify structures such as drowned reefs and beachrock lines.

Camargo et al. (2007) investigated the topography of the inner continental shelf off the Tamandaré municipality through